Adsorption of Heavy Metal Ions from Aqueous Solutions and Wastewater using Water Hyacinth Powder

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ABSTRACT

The adsorption of heavy metals on water hyacinth powder from both wastewater and aqueous solution was studied using batch experiments. The adsorption efficiency of water hyacinth powder was evaluated in this study. The levels of heavy metals in wastewater were in the range of 1.2-75.3 ppm for lead, 0.4-87.6 ppm for chromium, 0.1-63.5 ppm for nickel, 0.5-95.5 ppm for zinc and 0.8-52.7 ppm for cadmium. The levels of zinc, lead and cadmium were above the limits set by the write NEMA in full then bracket (NEMA) for discharge into the environment (0.01 ppm for cadmium and lead, 0.5 ppm for zinc). The adsorption efficiency of hyacinth powder was higher in aqueous solution than in wastewater while at low metal concentrations (0.1-3.2 ppm), the adsorption efficiency of water hyacinth powder was 100% in both wastewater and aqueous solution. The study showed that water hyacinth powder is a low cost adsorbent which could be used to remove heavy metals from wastewater and aqueous solution.

KEYWORDS: Wastewater, aqueous solution, heavy metals, adsorption, Water hyacinth

INTRODUCTION

Heavy metals are toxic, non-biodegradable and harmful contaminants that affect human beings and the environment (Azimi et al., 2017). Heavy metal pollution is increasing majorly because of the ever increasing industrialization. Harsh environmental problems which are caused by heavy metals have led to strict guidelines of wastewater release from the industries (Sajab et al., 2017). Various methods have been used in the removal of heavy metals from wastewater. However to attain cost-effective industrial wastewater treatment, adsorption can be the inexpensive method which is widely used (Gupta and Mahindrakar, 2015). It involves the transfer of the pollutants from the bulk to the active sites of the adsorbent (Hegazi, 2014). Although activated carbon has huge adsorption capacity, it is an expensive technique. Several studies have reported great adsorption capacity of low cost adsorbent that is comparable to commercial adsorbents (Wani et al, 2015). Researchers have been investigating promising adsorbent and their applicability in wastewater treatment (Akhbari et al., 2015). Comparative study on efficiency of water hyacinth, water lettuce and vetiver grass has been reported. The study showed that the three plants have different abilities to eliminate water contaminants and the ability of each plant is influenced by factors such as climate, temperature etc (Gupta and Mahindrakar, 2015). In this study, water hyacinth was used as an economical adsorbent because of its abundance in Kenyan lakes and it requires minimal preparation before use. The aim of this study was to determine the concentration of lead, zinc, cadmium, chromium and nickel in wastewater sampled from different industrial sites in Nairobi and further to evaluate the adsorption efficiency of water hyacinth in the removal of these metal ions from aqueous solution and wastewater.

Material and methods

Water hyacinth was collected from a beach point on Lake Victoria. The water hyacinth stems were sliced into small pieces and washed with water. Distilled water was used to rinse the stems and then dried in the sun for 8 days. The water hyacinth pieces were further dried in an oven 110°C for 24.

The dry fractions of the water hyacinth stem were ground into powder. The particles were then sieved and graded using 300,425 and 2800 μm sieves and stored for subsequent use.

Preparation of the stock solutions

The amount of the reagent to be dissolved in a liter of distilled water to make an aqueous solution whose concentration was 1000 ppm was calculated according to equation 1.

\[ M = \frac{M_w x 100}{X_w x \frac{Y}{1808}} \]  \hspace{1cm} (1)

where \( M \) = mass (g) of the soluble salt which was weighed,
$M_w$ = molecular weight of the salt,  
$A_w$ = Atomic mass of the element of interest, $V$ = volume of the stock solution to be made, $P$= percentage purity of the salt. The calculated amount of metal salt which was weighed is shown in Table 1.

### Table 1 Amount of salts weighed (g) to make aqueous solution whose concentration was 1000 ppm.

<table>
<thead>
<tr>
<th>Metal</th>
<th>MF</th>
<th>MW</th>
<th>Amt (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pb</td>
<td>Pb (NO$_3$)$_2$</td>
<td>331.2</td>
<td>1.6311</td>
</tr>
<tr>
<td>Zn</td>
<td>Zn (NO$_3$)$_2$.6H$_2$O</td>
<td>297.48</td>
<td>4.7396</td>
</tr>
<tr>
<td>Cd</td>
<td>3CdSO$_4$.8H$_2$O</td>
<td>769.56</td>
<td>6.9861</td>
</tr>
<tr>
<td>Cr</td>
<td>Cr(NO$_3$)$_2$.9H$_2$O</td>
<td>400.15</td>
<td>7.9347</td>
</tr>
<tr>
<td>Ni</td>
<td>Ni (NO$_3$).6H$_2$O</td>
<td>290.80</td>
<td>5.0560</td>
</tr>
</tbody>
</table>

MF = Molecular formula, MW = molecular wt  
Amt = Amount weighed (g)

The amount weighed was then placed in a 1000 ml volumetric flask. 100 ml of distilled water was added and stirred. 30 ml of 1M HNO$_3$ was added and the solution was swirled. Distilled water was added to the mark.

The working standards for the AAS were obtained from standard commercial solution by dilution. 0.1M HNO$_3$ and 0.1M NaOH were used to adjust the pH of the stock solutions.

### Collection of the wastewater samples

Samples of wastewater were collected from Sites A (Battery manufacturing Company), Site B (Paints manufacturing Company), Site C (Steel manufacturing Company) and Site D (Plastics manufacturing Company) in industrial area in Nairobi County. Sampling was done using pre-cleaned polyethylene bottles that had been washed with distilled water and rinsed with HNO$_3$ and labeled. The samples were then stored in a refrigerator for subsequent analysis.

### Digestion of wastewater samples

300 ml of the wastewater samples were first treated with 3 ml dilute nitric acid, shaken thoroughly and allowed to stand for 24 hrs. The samples were gravity filtered using Whatman paper (No. 40). The filtrate was shaken well before taking 100 ml which was added to a beaker using a 100ml volumetric flask. To the 100 ml sample, 3 ml of aquaceraigia was added. The resulting mixture was covered using a watch glass.

A blank was also prepared by adding 100 ml of deionized water into a beaker, followed by 3.0 ml of aquaceraigia and covering the beaker with a watch glass. The samples were heated at 90°C for 3 hrs in a fume hood until the volume of the sample was reduced to 20 ml. The samples were allowed to stand for 30 minutes to cool. The watch glass was removed and the sample was dispensed to a 100 ml volumetric flask. Deionized water was added to the samples to make it to 100 ml. The sample was stirred for 5 minutes, filtered and the filtrate was used for the determination of heavy metal concentration using AAS.

### Determination of heavy metals in the samples using AAS

The standards were then run in the instrument, read and a linear calibration curve for each metal was obtained. The samples were then run in AAS and concentration of heavy metals obtained from linear line.

### Removal of heavy metals from wastewater

100 ml of digested sample was added to 0.5g of powdered water hyacinth contained in a series of beakers. The mixtures were stirred continuously for 5 minutes. The samples were allowed to stand for 2 hours for adsorption to occur. The mixtures were filtered and the residual concentration ($C_r$) of the selected heavy metal ions contained in the filtrate established using the AAS. The adsorption efficiency of water hyacinth in the removal of selected metallic ions from wastewater was computed using Equation (2)

$$q = \frac{C_1-C_2}{C_1} \times 100 \ (2)$$

Where $q$ = adsorption efficiency of water hyacinth, $C_1$ = concentration of the selected heavy metals in wastewater; $C_2$ = residual concentration of the selected heavy metals after adsorption.

### Removal of heavy metals from aqueous solution using water hyacinth

The experiments were carried out using 100 ml of aqueous solutions whose metal concentrations varied from 75.3 ppm for lead, 52.7 ppm for cadmium, 95.5 ppm for zinc, 63.6 ppm for nickel and 87.6 ppm for chromium. Each of the metal concentrations was added to 0.5g (<300 μm) of powdered water hyacinth contained in a series of 500 ml beakers. The mixtures were stirred continuously for 5 minutes and allowed to stand for 2 hours for adsorption to occur.

The mixture was filtered and the concentrations ($C_2$) of selected heavy metal ions were determined in the filtrate using AAS. The adsorption efficiency of water hyacinth in the removal of selected metallic ions from wastewater was computed using Equation (2).

### Results and discussion

#### Concentration of Heavy metals in wastewater

The concentration of the heavy metals in the wastewater samples at sites A, B, C, and D are shown in Table 2.

### Table 2. Concentration (mg/l) of heavy metals in wastewater

<table>
<thead>
<tr>
<th>Site</th>
<th>Pb (mg/l)</th>
<th>Cd (mg/l)</th>
<th>Zn (mg/l)</th>
<th>Ni (mg/l)</th>
<th>Cr (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>68.5 ± 0.1</td>
<td>52.7 ± 0.1</td>
<td>0.75 ± 0.01</td>
<td>0.2 ± 0.02</td>
<td>0.51 ± 0.01</td>
</tr>
<tr>
<td>B</td>
<td>75.3 ± 0.2</td>
<td>40.0 ± 0.5</td>
<td>95.5 ± 0.2</td>
<td>0.14 ± 0.06</td>
<td>0.51 ± 0.01</td>
</tr>
<tr>
<td>C</td>
<td>1.2 ± 0.03</td>
<td>0.98 ± 0.1</td>
<td>48.8 ± 0.3</td>
<td>63.5 ± 0.2</td>
<td>87.6 ± 0.5</td>
</tr>
<tr>
<td>D</td>
<td>3.2 ± 0.01</td>
<td>0.88 ± 0.6</td>
<td>0.58 ± 0.02</td>
<td>0.11 ± 0.03</td>
<td>0.38 ± 0.01</td>
</tr>
</tbody>
</table>

Site A had very high levels of Pb and Cd. The high concentration of cadmium could be attributed to the use of Cadmium Oxide as a conductor in the manufacture of battery (Klein and Costa, 2007). Lead levels were high because of the use of lead metal and lead oxide as electrodes during manufacturing of batteries (Saatia et al., 2017). The high zinc concentration in sites B and C could be attributed to the use of ZnO and ZnCrO$_4$ as pigments in the manufacture of...
white and yellow paints respectively (Osmond, 2012). High Pb concentration in Sites A and B could be ascribed to the use of Pb(CO₃)₂ and PbCrO₄ in paints (Kessler, 2014). The high concentration of Cadmium in sites A and B could be due to the use of cadmium sulfide as a pigment in the manufacture of the yellow paints (Ogilo et al., 2017). The high concentration of chromium in sites B and C could be attributed to the use of Cr₂O₃ and Cr₂O₃·H₂O as a colorant in chrome green paints (Sabty-Daily, 2017). The high levels of Cr in site C could be as a result of chromium used in steel manufacturing (Nakamura et al., 2017). The high nickel concentration in site C could be attributed to the use of nickel in the manufacture of steel (Abdallah et al., 2017).

**Efficiency of water hyacinth powder in the removal of heavy metals from wastewater**

The effects of powdered water hyacinth (<300 μm) on the removal of heavy metals in wastewater were investigated and the results are shown in Figures 1-4.

Heavy metals with high concentration had lower percent efficiency of removal (Figure 1). This can be ascribed to the competition for the adsorption sites from other metals in the wastewater (Medellín-Castillo et al., 2017). This further confirms the effectiveness of water hyacinth powder in the removal of heavy metals in wastewater at low concentrations. Figure 2 shows the efficiency of water hyacinth in the removal of heavy metals from wastewater collected from site B. The trend is also the same as Figure 1.

Figure 3 shows the efficiency of water hyacinth in the removal of heavy metals from wastewater collected from site C. Again similar trend was observed.

![Figure 3: The effects of powdered water hyacinth (<300 μm) on the concentration of heavy metals in waste-water collected from site C (Steel manufacturing Company).](image)

Figure 4 shows the efficiency of water hyacinth in the removal of heavy metals from wastewater collected from site D.

**Adsorption of heavy metals on adsorbent in an aqueous solution**

The adsorption studies for heavy metals from an aqueous solution was carried out using the highest concentration for each metal based on the levels that had been determined in the wastewater for the various industrial sites (75.3 ppm for lead, 52.7 ppm for cadmium, 95.5 ppm for zinc, 63.6 ppm for nickel and 87.6 ppm for chromium) as shown in Table 2. The results were used to investigate the percentage efficiency of heavy metal elimination from the aqueous solution by water hyacinth powder as shown in Figure 5.

![Figure 4: The effects of powdered water hyacinth (<300 μm) on the concentration of heavy metals in waste-water collected from site D (Plastic manufacturing Company).](image)
Figure 5: Efficiency of water hyacinth powder in the removal of heavy metals from aqueous solution.

In the studies where percent efficiency of removal of the heavy metals was calculated for the wastewater (Figures 1 to 4), heavy metals with low concentrations had the highest % efficiency removal however in the aqueous solution where individual metal concentrations existed on their own, the removal trend was different (Table 3).

Table 3: Efficiency of water hyacinth powder in the removal of heavy metals from both wastewater and aqueous solution

<table>
<thead>
<tr>
<th>% Efficiency of Heavy metal removal</th>
<th>wastewater</th>
<th>aqueous solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nickel (63.6 mg/l)</td>
<td>66.4</td>
<td>60.4</td>
</tr>
<tr>
<td>Zinc (95.5 mg/l)</td>
<td>78.7</td>
<td>74.9</td>
</tr>
<tr>
<td>Cadmium (52.7 mg/l)</td>
<td>76.9</td>
<td>68.9</td>
</tr>
<tr>
<td>Lead (75.3 mg/l)</td>
<td>81.1</td>
<td>71.0</td>
</tr>
<tr>
<td>Chromium (87.6 ppm)</td>
<td>73.1</td>
<td>70.2</td>
</tr>
</tbody>
</table>

The study showed that the percent efficiency in the removal of the heavy metal ions was higher in aqueous solution than in the wastewater irrespective of the concentration used. This could be attributed to external competition for the adsorption sites from other metal ions in the wastewater (Park et al., 2015).

Conclusion

The study showed that the levels of zinc, lead and cadmium in wastewater were above the limit recommended by NEMA. The percent efficiency to remove heavy metals from both wastewater and aqueous solutions by water hyacinth powder at low concentrations of heavy metal was higher than at high concentration. Hence, water hyacinth E.crassipes can be used to remove heavy metals in wastewater released from the industries. The adsorption efficiency in aqueous solution was higher than the adsorption efficiency in wastewater. Cd and Pb concentrations in sites A, B were very high; Zn in B, and C were very high; Ni in C was very high; Cr in B and C were very high.

Abbreviations

NEMA: National Environment Management Authority; AAS: Atomic Absorption Spectrophotomer; HNO₃: Nitric acid; NaOH: Sodium hydroxide; pH: potential hydrogen; ppm: parts per million; M: Molarity; Mg/l: milligram per liter; ZnO:

Zinc Oxide; ZnCrO₄: Zinc Chromate; Pb: Lead; Pb(CO₃)₂: Lead Carbonate; PbCrO₄: Lead (II) Chromate; Cr₂O₃: Chromium (III) Oxide; Cr₂O₃H₂O Chromium (III) Oxide hydrate; Cd: Cadmium; Cr: Chromium, Zn: Zinc; Ni: Nickel

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Authors’ contribution

John Onam Onyatta and Amir Okeyo Yusuf designed the experiment. Joseph Munene Mwaniki collected the samples, carried out sample preparation, analysis and wrote the manuscript. John Onam Onyatta and Amir Okeyo Yusuf revised the manuscript critically for intellectual content.

Competing interests

The author declares that they have no competing interest.

References


